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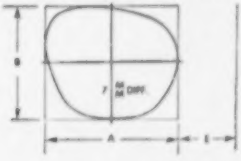

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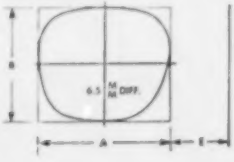

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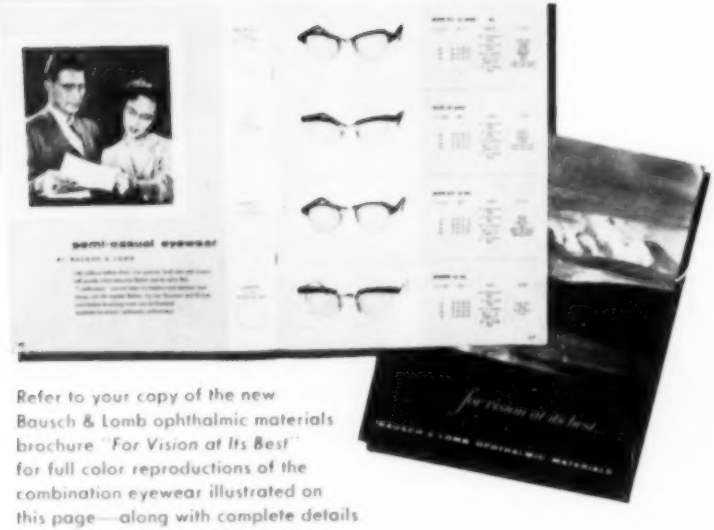

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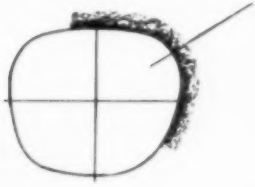

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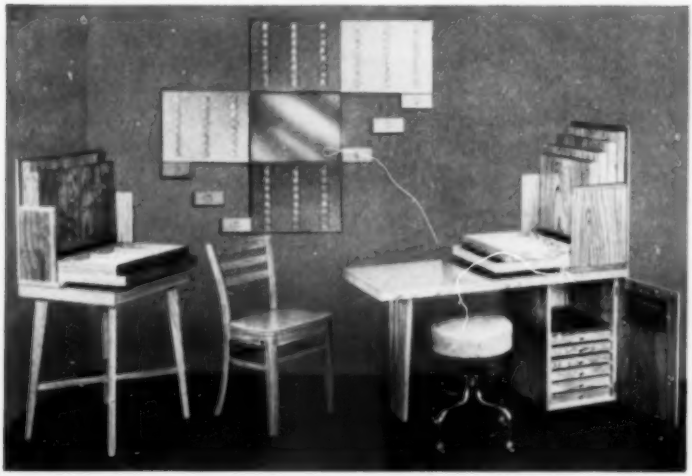

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Vol. 33 February, 1956 No. 2

THE NATURE OF THE PHOTORECEPTOR PROCESS

David D. Michaels†
Illinois College of Optometry
Chicago, Illinois

"The central hypothesis has often been accepted, as a makeshift, when peripheral analysis has been judged impossible. Thus the difficulty of explanation was avoided by transferring it to a region where, nothing being clear, all appeared possible. . . ."
Henri Pieron

One of the most fascinating areas in visual science is the study of the conversion of appropriate energy into those nerve messages which trigger an awareness of our visual environment. It is fairly easy nowadays to demonstrate that, under certain conditions, stimulation of the retina results in a recordable electric activity in those nerve elements conducting to the occipital lobe. These electric changes have a character and individuality which lead us to believe that they are the components of a coded message. Such a view is strengthened by the observed similarity of the electric events to various sensory aspects of vision such as flicker, adaptation and threshold measurements.

The conversion of energy within the retina must, consequently, be accomplished in such a manner that a definite isomorphism will be retained between the totality of events in the visual field and the characteristics of the nervous message which represents it. Such an isomorphism is insured on the one hand by the rather rigorous arrangement of optical elements of the eyeball and, on the other, by the discreteness and configuration of the nerve fibers within the visual pathway.

It is quite apparent, therefore, even from a preliminary inspection, that this energy conversion problem is not a simple one. While the physicist has worked out many of the optical aspects of the problem and the neuro-anatomist has supplied data concerning the arrangements and connections of neurons within the visual paths, we have relatively little knowledge regarding those events which mediate between the two.

The conversion of the adequate stimulus, namely, radiant energy

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†Optometrist, M.S., D.O.S., Chairman, Department of Biological Sciences, Fellow, American Academy of Optometry.

of specific intensity and wavelength, into nerve impulses seems to involve two distinct steps. In the first step, the radiant energy, after having been filtered through the ocular media, is absorbed by the photoreceptor cells—the rods and cones. Here, a photochemical reaction takes place, the extent of which is quantitatively related to the total number of energy quanta absorbed. In the second step, the photochemical reaction sets off a series of events which culminate, as a result of electron transfers, in those electric disturbances concomitant with neural activity.

While most modern students of vision accept, at least in part, the photochemical interpretation of the initial events of the light sense process, it has not been immune to criticism. This criticism has been directed particularly at certain constants in the photochemical equations. These constants were determined by fitting the equations to empirical data. However, the fact that such equations contain constants seems to reflect nothing more than the logical consequence of searching for the "invariables" in nature. The numerical values of such constants can, after all, only be obtained by comparing the equations to empirical data. Different experimental investigations have not lead to the same numerical values. This results from two causes. First, the data of investigators have not been comparable with respect to the factors which can be controlled. One is reminded of a similar situation in physical chemistry with respect to equations of state. The behavior of actual gases as compared to an ideal gas can be described by a number of equations (with varying numbers of constants) which are more or less complete, critical and detailed, depending on the nature of the data and the use to which they will be put. Second, it seems to have been forgotten that such photochemical equations often reflect only inductive reasoning from a "model." When a model is postulated to account for a large number of experimental facts, it does not necessarily depict the real state of affairs. It is nothing more than the representation of ordered but as yet unexplained phenomena in terms of concepts already understood. Such a view allows for the possibility of alteration in the model structure without invalidating the experimental facts on which it is based.

The photochemical view of photoreceptor processes is still largely in the model stage for many reasons to be described. No one seriously doubts that the initial visual reaction is photochemical but rather the quantitative details have been questioned. Nevertheless, we can agree with Adler (1950, p. 467):

> The photochemical theory has proven a useful tool in the acquisition of knowledge in this field. It will not have lost any of its value if, in the future, it is found inadequate to explain the more complicated processes occurring in human photoreception.

Having disposed of these preliminary objections one may examine some problems which are more to the point. Clearly, a photochemical theory depends to a great extent on the assumption that rhodopsin and iodopsin (or at least some photochemical in the cones closely related to the rod substance) are the basic triggers which initiate the nerve impulses. Thus, any attack on the role played by these photochemical substances is a severe blow to any photochemical model.

In 1942, Walls (p. 75) wrote:

> Rhodopsin is still widely regarded as the absolute essential photochemical substance for rod activity. Even this is an unnecessary belief, since rhodopsin may be nothing more than a sensitizer, so powerful that its action masks that of another essential material so completely that the brightness of lights are directly related to their effects upon rhodopsin.

In a similar vein, Hartridge (1950), in reviewing the recent experimental evidence comes to the following conclusion (p. 385):

> Returning now to visual purple, we know that it is bleached by light but in view of what has been stated above, the idea which presents itself is that this bleaching is an unwanted side effect which is not fundamental to vision: and that a more permanent dye might be expected to produce the same or even better results.

Now, in part, the evidence to which Hartridge refers is that presented by Bliss (1948). Bliss isolated the red pigment of the squid eye which he named Cephalopsin. He found this pigment to be *light-stable* in solution but photosensitive in the presence of protein denaturants such as alcohol and formalin. The end product appears to be Retinene. From this, Bliss concluded that the bleaching of visual purple is a specialization, the absence of which may have no direct bearing on the efficiency of a visual pigment. Wald (1951) however identified Cephalopsin with the recently isolated meta-rhodopsin thus accounting for its properties. Hartridge points to two other facts to support his conclusion. First, a large amount of light is required to bleach visual purple rapidly and second, in the case of photographic plates, permanent and not light fugitive dyes are employed to confer light sensitivity.

With regard to the first point, Wald has shown, however, that the light reaction is essentially the bleaching of rhodopsin to lumirhodopsin, a process requiring little time and presumably little energy. As regards the second point, photographic plates exposed to light result in a "latent," almost invisible image which develops only after the slower dark reactions. A similar change occurs in the retina when lumirhodopsin is produced (Wald, 1951).

The outstanding stumbling blocks for a photochemical theory continue to be (1) lack of information regarding the cone substance and the nature of chromatic brightness discrimination and (2) the manner by which the decomposition products of rhodopsin as well as the cone

substance act as nervous excitors. Although these objections are universally recognized, we can agree with the observation made by Tansley in 1939:

> It is on circumstantial evidence only that we base the belief that our visual perceptions at low illumination are the result of the reaction of visual purple to light. If, however, we take all the facts together, not only do they make an extremely convincing case, but, up 'till now, nothing has emerged from the study of visual purple which might cause us to look on this theory with suspicion.

The researches of Hecht and his co-workers since 1918 have, without doubt, been the greatest impetus for the photochemical interpretation of a large number of visual functions. Hecht's basic studies were summarized by him in 1934 and 1937. They were primarily confined to the visual responses of certain invertebrates, "Mya," a clam and "Ciona" a sea squirt. Both of these organisms respond to light by a qualitatively invariable retraction of their syphons. They are thus convenient for studying the effect of light stimulation on relatively simple visual systems which are further uncomplicated by neural interaction effects and therefore, are more likely to be restricted to pure photochemical processes.

With Ciona, intensity was varied and the time necessary to just cause a response was measured. With Mya, the time was varied and the least intensity was measured. The product I x t, for short flashes, was found to be a constant in both cases, being 5.62 m.c.—seconds for Mya and 4.75×10^3 m.c.—seconds for Ciona. Further, the temperature coefficients of the reactions were found to coincide with those characteristic of simple photochemical reactions (Hecht, 1925).

The interval from beginning of exposure to the beginning of the resultant response is called "Reaction Time" and is a constant value under constant conditions. It varies inversely with intensity but may not be reduced to less than 1.5 seconds (for Ciona) which represents its minimum duration or the maximum rate of the underlying reaction. For a constant intensity, if the exposure time is shortened, the reaction time will not change, up to a critical value—the "Sensitization Period." Exposures shorter than this critical sensitization period will cause the reaction time to increase.

On the basis of these time relations, the reaction time is considered to be composed of two sub-parts. (1) A sensitization period during which the animal must be exposed (for minimum reaction time) and (2) A "Latent Period" during which it need not be exposed for a response to occur. The latent period is clearly uninfluenced by light since it *may* occur in the dark while the sensitization period is directly influenced by the stimulating light: the higher the intensity, the shorter

the sensitization period—within the limits of the Bunsen-Roscoe Law.

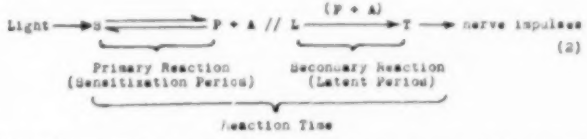
In view of these results, it was postulated that two more or less independent reactions were involved in each of these time intervals. The sensitization period represents the time for the accumulation of photochemical decomposition products and the associated removal reaction. The latent period which takes up most of the reaction time is occupied by a secondary process. This latent period time interval may be due to the fact that (1) the decomposition products are produced at one point in the sense cell and are effective at another, a physical diffusion process, or (2) it is taken up by a secondary non-photic chemical process (since it may occur in the dark).

In order to decide which of these two alternatives was the more likely, Hecht subjected the system to a temperature change and measured the velocity of the latent period. If, for example, the reaction followed quantitatively the equation of Arrhenius:

$$\log_e \frac{V_2}{V_1} = \frac{u}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \qquad (1)$$

this would be in accord with the second (chemical) alternative. In the equation V_2 and V_1 are the velocity coefficients at the absolute temperatures T_1 and T_2; R is the gas constant (in heat units) and u is the energy of activation. It was found that u = 19,680 calories and corresponds to a temperature coefficient of about 2.7 which is in accord with the chemical rather than the diffusion alternative of the latent period process, the products of which accumulate in the sense organ and set off the afferent stimulus to the central nervous system. Such a mechanism accounts ideally for the "trigger" like response in which a relatively small amount of radiant energy sets off a considerable neural effect.

The symbolic representation of these reactions as postulated by Hecht looks like this:



S is the photosensitive substance: P and A are the decomposition products: L is an inactive substance activated in the presence of P + A and T is an active agent capable of initiating the nerve impulse.

Hecht pointed out that the primary reaction may be pseudo-reversible of the form:

$$S \longrightarrow P + A + B \quad (3a)$$
$$S \longleftarrow P + A + C \quad (3b)$$

In this form the cycle is not closed since a substance which is not one of the decomposition products is required in the rebuilding process. If this were not the case, vitamin A deficiency, for example, would have no deleterious effect because all of the necessary vitamin would be available from the decomposition process. Since such a deficiency can be shown to raise significantly the visual threshold, the cycle cannot be closed. The rebuilding process must then require either an entirely new substance or the refurnishing of substances such as vitamin A which, once formed, are dissipated into the contiguous tissue.

The rate of the secondary reaction (L $\longrightarrow$ T) is dependent on the concentration of P + A which Hecht calls "x" and x is in turn dependent on the intensity, I, and the time, t, within the limitations of the Bunsen-Roscoe law as applied to the primary photochemical reaction. The sensitization period was found to be governed by this law for short exposure times (less than 3 milliseconds) and for intensity values below a certain minimum (the absolute intensity threshold). These relations for Mya are given in Table I.

TABLE I

I	t	I • t
54	0.104	5.62
76	0.073	5.55
112	0.053	5.94
194	0.030	5.82
238	0.023	5.47
334	0.016	5.34

Relation between intensity, I, and time, t, for short exposures to produce a minimal sensory response in the clam Mya. After Hecht, 1919.

This illustrates that for a given photochemical effect E (or concentration x) a constant, minimum amount of energy is necessary regardless of its time distribution:

$$I \times t = C \quad (4)$$

If either the intensity or the time is increased, while the other remains constant, the photochemical effect will be greater, x will be higher and the rate of the secondary reaction proceeds faster. As a result, the latent period is shortened and so is the reaction time of which it is a part within the limits defined above. It was found experimentally that when the reciprocal of the sensitization period of Ciona is plotted against intensity, a straight line relation is obtained. Similarly, the reaction time varies inversely with intensity. The latent period is, of

course, inversely related to the rate of the secondary reaction which, being dependent on x, makes the latent period similarly (but indirectly) related to the light intensity. An analogous argument may be presented when time is substituted for intensity.

When the secondary reaction proceeds faster as the result of an increase in either time or intensity, more T must accumulate which will presumably result in a greater frequency of nerve impulses to the higher visual centers. Since this frequency determines the experienced brightness we have:

$$I \sim \text{Rate}_{x_1} \rightarrow T \sim \frac{1}{L.P.} \sim \text{Frequency} \sim \text{Brightness} \qquad (5)$$

Now, when we introduce a proportionality constant (K) into equation 5 we derive:

$$\text{Experienced brightness} = KI \qquad (6)$$

Equation 6, however, at least suggests the Fechner function* which can be derived by experimental sensory methods.

We have seen that below a certain intensity value no response (contraction of syphon) will occur regardless of the length of the exposure time. At this "absolute intensity threshold" (also expressable as a certain value of x, say x_1) the decomposition products whose concentration is initially less than x_1 do not accumulate (as, for example, the do in a photographic plate). A photographic plate may be bleached by infinitesmal intensities providing only the exposure time is long enough.

An analogy may be helpful. If one wishes to fill a bathtub whose outlet pipe is not covered, then the rate at which the fluid enters must be at least a certain minimum determined by the size of the uncovered outlet pipe. Fluid entering at a rate less than this minimum will never fill the tub. In the retina this minimum flow rate is the absolute intensity threshold or the "internal" threshold of the sense cell. The open hole in our bathtub may represent one of two things. Either (1) the decomposition products are entirely dissipated and lost into the contiguous tissues at a certain rate or (2) they recombine (with some minor new additions) to form the original photosensitive substance. In order to decide between these two alternatives, Hecht measured the dark adaptation of Mya at three different temperatures and calculated the velocity constant, K_2 (equation II), of the second order reaction. The results are given in Table II.

*Fechner, the so-called father of psycho-physics, was the first to realize the implications of Weber's experiment. From Weber's conservative expression he derived the equation $S = k \log I + C$ and, by thus placing sensation on one side of an equation and physical stimulus values on the other, started a controversy which has not ended to this day.

TABLE II

Temp. in OC	Velocity Constant K
11.5°	0.069
16.2°	0.131
21.9°	0.217

Dark Adaptation of Mya at three different temperatures. After Hecht, 1925.

The temperature coefficient calculated from these values is roughly 3.1+ for 10.4°. Now, according to Vant' Hoff's empirical rule, if the reaction is a chemical one, the temperature coefficient should be precisely around this value (i.e., 3 for 10°). On the basis of these results, the second (chemical re-combination) alternative is taken as the more likely process which prevents the "below-absolute threshold" light intensities from accumulating in the retina. Thus the failure of the Bunsen-Roscoe law to hold at low intensities implies the reversibility of the primary reaction. In order to illustrate these relations more rigorously Hecht presented the following argument:

Assume an intensity I stimulating the eye. Light will be absorbed by the photosensitive substance S which will be changed from its initial concentration "a" to "(a—x)" when any decomposition products are formed. The velocity (V_1) of such a reaction follows from the mass-action law* and we obtain equation 7.

$$V_1 \ (S \longrightarrow P + A) = K_1 \ (I) \ (a—x) \qquad (7)$$

Where K_1 is the velocity rate incorporating the absorption coefficient. This is the first order reaction which involves the concentration of only one substance, one molecule reacting at a time. Thus the velocity (V_1) will be measured by the amount of substance changed (x), divided by

*The mass action law is a quantitative statement which relates the velocity of a reaction to the concentration of its reactants. In the hypothetical reaction A + B $\rightleftharpoons$ C + D, the number of molecules reacting per unit time is proportional to the number of collisions between them. The chances of collision will be $N_a \times N_b$ where N_a and N_b represent the number of A and B molecules respectively. Similarly, N_c and N_d will represent the chance of collision for the C and D molecules. When N is expressed in the proper units, it expresses the concentration and since the rate of the reaction is determined by the number of collisions we have: $Rate_1 = K_1(A)(B)$; $Rate_2 = K_2(C)(D)$ where the brackets indicate the molecular concentration (moles/liter) and K_1 and K_2 are proportionality constants. When the system is in equilibrium both reactions proceed at an equal rate: $Rate_1 = Rate_2$ or $K_1(A)(B) = K_2(C)(D)$ or $\frac{K_1}{K_2} = \frac{(C)(D)}{(A)(B)}$. Since K_1 and K_2 are both constants, the ratio $\frac{K_1}{K_2}$ is constant and can be represented by K_{eq}, the equilibrium constant. In general, for the reaction $nA + mB \rightleftharpoons pC + rD$ where m, n, p and r are small whole numbers, $Keq = \frac{(C)^p \ (D)^r}{(A)^n \ (B)^m}$.

the interval of time (t_2—t_1) required for the change. If the time is infinitely short (dt), then an infinitely small amount of substance (dx) will be changed during that period:

$$V_1 = \frac{dx}{dt} = K_1 \ (I) \ (a—x) \qquad (8)$$

The velocity of the reverse reaction, that is the primary dark reaction, is given by (V_2) which, again from the mass action law, is:

$$V_2 \ (S \xleftarrow{\qquad} P + A) = K_2 \ (x^n) \qquad (9)$$

Where K_2 is another constant incorporating the absorption coefficient and n represents the number of different decomposition products. In Hecht's scheme, the number of decomposition products is at least two. Presumably, these are present in equal concentration. Equation 9 is then determined by the concentration of two reacting substances, i.e., it is bimolecular and, since the concentration of both substances must be considered, it is of the second order. Since the concentration of both P and A are expressed by x we have:

$$V_2 = \frac{dx}{dt} = K_2 \ (x^2) \qquad (10)$$

If we *integrate* this equation and set t = O, then x = O and we have:

$$K^2 = \frac{1}{t} \bullet \frac{x}{a \ (a—x)} \qquad (11)$$

From equation 11 the reaction rate may be determined. Now, in order to obtain the *actual* velocity of the primary decomposition (light) reaction, the velocity of the reverse (dark) reaction must be subtracted from the velocity of the bleaching reaction. This will give us the rate $(\frac{x}{t})$ at which P and A accumulate:

$$(\text{Rate at which P + A accumulate}) = \frac{x}{t} = V_2 — V_1 \qquad (12)$$

Substituting expressions 8 and 9 into equation 12 we have:

$$\frac{x}{t} = K_1 \ (I) \ (a—x) — K_2 \ (x^n) \qquad (13)$$

which may be re-arranged to better illustrate the relations between intensity, time and decomposition products to give:

$$I \bullet t = \frac{x}{K_1 \ (a—x)} + \frac{K_2 x^n}{K_1 \ (a—x)} \bullet t \qquad (14)$$

Since x is taken as a constant for absolute intensity threshold (i.e., x_t) then (a—x) will also be constant and, of course, K is constant so we

can substitute the arbitrary constants: $C = \frac{x}{K_1 (a-x)}$ and $D = \frac{K_2 x^n}{K_1 (a-x)}$ providing we retain the threshold conditions:

$$I \bullet t = C + D \bullet t \qquad (15)$$

Now, for short exposures, t is small and the constant D is small since V_2 must be less than V_1 or, it would either require enormous intensities or a very long time for any P + A to accumulate. Thus, equation 15 reduces to:

$$I \bullet t = C \qquad (16)$$

which is identical to equation 4 and is, of course, the Bunsen-Roscoe law which does hold true for short exposures. Baunstein, 1923, determined these values for the human eye.

TABLE III

I	t	I • t
1	.0210	.021
2	.0098	.020
4	.0047	.019
8	.0024	.019
16	.0012	.019

Relation between intensity I and time t for short exposures to produce minimal responses in the human eye. After Braunstein, 1923.

For longer exposures the more involved expression (15) must be used. Thus when appropriate constants are inserted into this equation, Blondel and Rey (1911) found it to hold for exposures up to 3 seconds. Their results are given in Table IV.

TABLE IV

t	I • t (found)	I • t = 0.065 +0.31t
3.00	1.00	1.00
1.00	0.372	0.375
0.30	0.156	0.158
0.10	0.102	0.096
0.30	0.070	0.074
0.01	0.068	0.068
0.003	0.072	0.066
0.001	0.064	0.065

Comparisons between I • t for the eye for a large range of exposures, as measured and computed. After Blondel and Rey, 1911.

When the exposure time is infinitely long, however, then, if the Bunsen-Roscoe law held true, one should be able to let I approach O and still obtain a visual sensation or, in the case of Ciona, a syphon contraction. It was found, however, that while this may occur for the photographic plate, no such results can be obtained from the living

photoreceptor. Specifically, equation 13 represents the rate at which P and A accumulate and, if one lets t approach infinity, then $\frac{x}{t}$ approaches zero and equation 13 reduces to:

$$[K_1 (I) (a-x)] = [K_2 (x^n)] \quad (17a)$$

or

$$\frac{K_1}{K_2} (I) = \frac{x^n}{a-x} \quad (17b)$$

It will be seen that equation 17b does not include time at all but is instead regulated by the variables x and I of which only the latter is independent. This is precisely what one might have expected on the basis of the experimental evidence. At absolute intensity threshold, where t approaches infinity, intensity and not time is the *limiting* factor.

It should be obvious that equation 17b also represents the "stationary state" or equilibrium condition. When the eye becomes adapted to a particular intensity, $V_1 = V_2$ and as one would not expect any further decomposition product accumulation, the ratio $\frac{x}{t}$ reduces to zero.

The photochemical theory as postulated by Hecht, *et al.*, presented a very powerful argument. The present discussion of it has indicated that, like any good hypothesis, it is not only in agreement with many observed facts but is capable of generating a large number of implications which may be verified experimentally. The general success of the theory over the past 30 years may be attributed to its capacity to conform to empirically obtained data, arbitrary constants notwithstanding. Some of the applications of the theory to such areas as visual adaptation, brightness discrimination or intermittent stimulation are beyond the scope of the present paper and have been described elsewhere (c.f. Michaels, 1952a, 1953b).

It remains to evaluate this photochemical scheme in terms of modern sensory and chemical data. While all the ramifications of the theory have not been discussed, one is nevertheless able to estimate some of the difficulties which have come up, what steps have been taken to meet them and how this has affected the reliability of the hypothesis.

The first difficulty arises in connection with the substitution of known chemical processes for the symbolic representation as given in equation 2. The symbol "S" represents the photosensitive substance of

the rods as well as of the cones. Otherwise the theory would be a "special case" for scotopic vision and would not represent the general situation at all.

As regards scotopic vision, current research has tended to confirm that S is, indeed, rhodopsin. The objection that the primary reaction was much too slow to account for the small time interval taken up by the sensitization period (for man) may be considered satisfactorily accounted for by the recently discovered breakdown to lumi-rhodopsin. The slower latent period process is no doubt the result of the "dark" reactions in which lumi-rhodopsin decomposes to retinene and opsin. With prolonged and excessive light exposure the latent period will probably be found to lengthen as a separate function depending on the slower resynthesis from the Vitamin A + opsin stage of decomposition. The earlier studies of visual purple by Hecht (1925) led him to the following conclusions which he cited as support for the primary reaction: (1) Rate of bleaching is a function of the concentration and proceeds according to a monomolecular isotherm. (2) The reaction is simple, without induction period and after effect and consequently flashes of light may summate photochemically under certain conditions. (3) Effect of temperature on bleaching is practically nil, which indicates the reaction to be endo-energetic and direct with no intervening side reactions. (4) The velocity constant of the bleaching reaction is a linear function of the intensity of the light.

All this evidence relates to scotopic vision. When one considers the events which occur in the cones the matter is not so simple. The fact that Hecht used the same symbol for the photopigment of both rods and cones leads one to assume that he regarded the two substances as closely allied. Current research is in accord with such a view. It is in fact suspected that the cone pigment may be nothing more than a slightly altered bond structure of the rhodopsin molecule. Specifically Hecht had this to say regarding the cone substance:

> All this information renders it highly probable that so far as rod vision is concerned it has been possible to isolate and, to a certain extent, study independently the substance S. What this substance may be for the cones, one cannot say at present. I once thought with Weigert and Hering that it might also be visual purple in a more dilute form, and I explained the difference between the spectral position of visual purple on the basis of Kundt's rule. But now I doubt whether such an hypothesis is fruitful and am more inclined to believe that the sensitive substances in the cones are not visual purple though they may be related to it chemically.

This was in 1934 and there is not too much more one can say today in 1954. The cone substance is very likely similar to iodopsin which is, in turn, very similar to Rhodopsin. As yet, however, we know almost nothing of its decomposition process. This state of affairs is largely due to technical difficulties in isolating the substance. It has in

fact been isolated "by difference" only from the chicken and never from a human retina. Finally the cone substance may be complicated by the possible presence of some sort of chromaticity detector. Preferably, following the three-component notion, this will be a three-factor one: that is, at least 3 different cone substances distributed in 3 different types of cones or collectively present in each cone. If color vision is photochemically determined, some provision must be present for the differential sensitivity of the cone substance. Only in this way could the cones send out impulses which vary not only in frequency but in pattern. What the relation of the photoreceptor process is to such patterns has never been made clear.

Another difficulty which arises for the photochemical theory accrues from the interpretation of the initiation of the nerve impulse. The presumably irreversible secondary reaction is purely speculative and was originally postulated to account for the latent period time interval. Now, nothing like a substance L or T has ever been identified in the sense that the primary decomposition products have. The secondary process is probably chemical rather than a simple diffusion process because its reaction rate is a linear function of the concentration "x" and it is affected by temperature according to the Arrhenius equation. For the rhodopsin system, if the primary decomposition products are retinene and opsin, it would require that one or both of these react on some third substance. This third substance would consequently be changed from an inactive to an active state. As a result of this activation, it is required that the substance initiate the nerve impulse. From what we know of nerve impulses, this means essentially, that a change in electrical potential results from such an interaction. But it was never made clear in the symbolic representation, whether P and A are reactants or catalysts in this activation.

The search for such a third substance in the retinas of various animals has so far brought no success. It now seems unlikely that such a substance will ever be found. This would then require that either retinene or opsin take the place of L. The first is the more likely possibility since opsin is a relatively inactive protein carrier and the discovery of lumi-rhodopsin as the decomposition product of the primary light reaction and retinene as the product of the dark reaction (at least the short duration type) supports such a point of view. This still leaves the problem of T. As a first approximation, one might assume that there are two forms of retinene, an active and an inactive. This seems unlikely from what is known of its chemical properties. In 1930, Troland considered this matter and came to the following conclusion (Vol. II, pp. 127-8):

Now considerable difficulty seems to attach to Hecht's conception of the secondary reaction in its application to the human eye, because of its metabolic requirements. It is evidently not a reversible process, but it would seem that its end product must be capable of very rapid elimination. . . . Evidently we have the further requirement that large quantities of L should be available to maintain the rapid, destructive process. It appears that the most satisfactory interpretation of the secondary process is that . . . P is capable of reacting with the membrane surrounding the receptor cell, so as to excite, or to increase the excitability of the latter. The second process involves two phases, first the diffusion of P to and into the membrane and second, its reaction with the membrane. . . . The substance L may be identified with some aspect of the membrane structure itself, while T represents the excited state of this structure, or, at any rate, the increased permeability which sets off the impulse. The reaction L $\longrightarrow$ T is reversed when the membrane is rebuilt during relative refractory phase. . . .

It is most interesting to note that Wald, the outstanding authority on retinal photochemistry, in a recent paper (1949) comes to somewhat similar conclusions. He writes:

Nor is it intended that retinene be regarded as the product responsible for neural excitation. Carotenoids are by nature bland substances to which it is difficult to impute strong pharmacodynamic effects. A simple computation shows that rhodopsin bulks large in the total composition of the rod outer limb; and I should prefer to look for the source of excitation in the direct physical attack on the microstructure of the rods implicit in the bleaching process itself, rather than in the liberation of a specific stimulant.

Wulff (1943) has subjected Hecht's conclusions regarding the agent T to an experimental study. The animals used were normal and deganglionated grasshoppers. The animal was allowed to attain a state of maximal dark adaptation and was then stimulated, once every second, with a half second stimulus of light of the lowest intensity. The repetitive stimulation was continued until the constancy of the electrical response indicated that the eye had reached a state of equilibrium with that intensity. At this time a photographic record of the response was made. The stimulating intensity was then increased and the process repeated. The magnitude of the electrical response was then translated into micro or millivolts, converted to per cent of maximum and averaged. The concentrations for the various intensities were then calculated according to equation 17b. Their data is presented in Table V.

TABLE V

Log I	% conc. of x	Log I + Δ I	Normal Grasshopper	Deganglionated Grasshopper
—2.04	1.4	—2	4.7	.55
—1.04	3.86	—1	9.13	2.5
—0.04	10	0	32.3	12.8
0.96	28.5	1	54.4	36.4
1.96	62.	2	88.2	62.5
2.96	92.	3	97.2	88.5
3.96	99.	4	100.	100.

Data relating per cent concentration of P + A and per cent magnitude of the retinal action potential to stimulating intensity. After Wulff, 1943.

It is concluded that the magnitude of the retinal action potential is a linear function of the concentration of the photochemical breakdown products and that x is proportional to e.m.f. From this it is apparent that there is a distinct relationship between the retinal action potential and the photochemical events of the light adapted visual mechanism. The linear relationship between the extent of the photochemical reaction and the magnitude of the electrical response indicates that the photoproducts P and A are not the electromotive agents directly producing the potential for such agents always bear a logarithmic relation between their concentration and the magnitude of the potential. Wulff postulates instead that the linear relationship obtained indicates a typical relation of enzyme concentration to velocity of reaction where P and A or both are the enzymes and the e.m.f. is a measure of the reaction rate. The potential may then be the activating agent T.

These results have been criticized by Granit (1947) on the basis that the electroretinogram gives a direct expression of the concentration of photosensitive material only in some instances while the correlation is altogether lacking in others. Finally doubt is cast on theoretical conclusions applied to the vertebrate eye from data obtained on non-vertebrates which have never been shown to contain visual purple in their retinas.

In 1946, Jahn worked out a modification of Hecht's analysis in order to account for the difficulties which arise when it is applied to the data of sensory fusion for intermittent stimulation. It was postulated that "old" P + A has no active part in stimulation. Instead some active material (denoted by "E") is considered:

$$S \longrightarrow E \longrightarrow P + A \longrightarrow S \qquad (18)$$

From these considerations Jahn arrives at more satisfactory expressions for sensory fusion data which are then applied to other phenomena such as adaptation. Fry and Alpern (1946) have applied Jahn's modification to the analysis of the responses of a dark adapted photoreceptor. Byram (1944) has also developed a modified photochemical scheme. An evaluation of these modifications is, however, beyond the scope of the present paper.

The application of quantum theory to visual phenomena, particularly threshold fluctuations, has thrown yet additional light on certain characteristics of the operations of the photoreceptors. An extensive review and summary of this approach has been presented by Bouman (1950) and I have presented some aspects of this problem elsewhere (Michaels, 1952b). These studies have focussed attention on the statistical behavior of light quanta and have permitted quantitative

formulations in purely physical (rather than photochemical) terms. Although this very new area of what might be termed *"biophysical optics"* is still in its infancy, it has already resulted in important theoretical and practical formulations dealing with a variety of visual phenomena. These formulations are, however, outside the scope of the classical photochemical approach.

On the neurophysiological side, it is unlikely that the threshold of the visual cells are the sole determinants of excitation. On the contrary, the extensive convergence of rods to a single ganglion cell (a ratio which may reach values of 10,000 to 1 in the peripheral retina) gives ample evidence of neural interaction. Such synaptic relations as well as the presence of horizontal transmission elements may be expected to significantly alter the character of the nerve messages signalled to the cortex. For example, the pattern or nerve impulses mediated by single photoreceptors (e.g. in Limulus) is considerably simpler than the one obtained from eyes which exhibit synaptic relays. Even the latter, however, bear little obvious relation to the visual stimulus in the same sense as the electrical responses of the cochlea do to sound.

When one considers that the visual messages are the most important (at least numerically) of all those reaching the human brain one must admit that our knowledge of photoreceptor processes is of little value in an attempt to understand them. This is more serious than may be apparent at first glance. It means that no matter how willing the neurophysiologist, psychologist or statistical mechanic may be to supply us with convenient mechanisms by which complex patterns (symbolic or otherwise—e.g. Craik, Marshall and Talbot, Wienes, etc.) may be elaborated, our key link in this chain of events remains unclear. Analogously, the magnification of the microscope is still dependent on the objective; the extent of amplification is limited by the workings of the first thrermionic tube irrespective of what one does to the output of that tube. In this respect, the neural contribution can be only the *second* step in some form of symbolic transformation. The basic isomorphism, no matter how non-linear it may be, must already be contained in the signals elaborated by the photoreceptors. This follows from the fact that only these cells have any direct contact (receptivity) with the external environment. Nevertheless, this aspect of the problem has received little if any attention from workers interested in the field. While photochemical analysis of visual receptor processes has provided important information concerning energy conversion it has not yielded anything which would tell us how this is accomplished isomorphically. The solution of this problem must be left to the future.

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BOOK REVIEW

MY FIFTY YEARS IN OPTOMETRY—AN AUTOBIOGRAPHY. Albert Fitch, O.D., F.A.A.O. Volume I. Published by the Press of the Pennsylvania State College of Optometry, 12th & Spencer, Philadelphia. 406 pages. Illustrated. Cloth. $5. 1955.

In 1906, the author opened his own optometric office in Kensington, a part of Philadelphia. During the next few years he became active in optometric organizational matters and led a vigorous and successful fight to prevent optometry from becoming absorbed into medical practice. In 1918, while still in practice, with the help of a few associates, he founded the Pennsylvania State College of Optometry. He is president of the College.

Volume I covers the professional and school administrative life of Dr. Albert Fitch from 1906 to 1930. This was a period of great development in optometry and the author then, as now, played many important roles in the significant actions taken by the profession. Much of this volume is given over to daily correspondence dealing with the current optometric events and the book is a mine of useful and historical information on optometry between 1906 and 1930. The Foreword is by Professor George A. MacElree.

This material is reprinted from the ALUMNI BULLETIN, Pennsylvania State College of Optometry where it appeared serially. Volume II is now in preparation. Like Volume I, it will be most welcome.

CAREL C. KOCH

DESCARTES' CONTACT LENS*

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The future is said to be fashioned upon the foundations of the past, with our present day heritage being the sum of innumerable strivings of the philosophers and scientists of bygone eras. In this paper, a small portion of this inheritance shall be considered, that of the early history of contact lenses. The reader will readily note, in addition, that these early contact lens experiments were closely entwined with studies delving into the very nature of vision. The brilliant efforts of three men, Leonardo da Vinci (1452-1519), René Descartes (1596-1650), and Thomas Young (1773-1829), will be discussed and an attempt will be made to determine the position to be occupied by Descartes in contact lens history. However, before proceeding, the author wishes to thank Professor R. A. Dudragne of the Institut d'Optique de Paris for introducing him to the work of Descartes and to several of the associated concepts.

The first known contact lens was used by Leonardo da Vinci in about 1508, as was recently pointed out by Hofstetter and Graham.[1] But, as shall be demonstrated, the question of contact lens discovery is not resolvable in a straight-forward or simple manner. Leonardo's lenses were recorded for posterity in the "Codex of the Eye" where one finds the bulk of his philosophical and investigative work on vision. In Folio 3, verso (as translated by Ferrero[2]) there appears the following passage:

ABOUT THE WAY TO MAKE THE EXPERIMENT TO SHOW HOW THE VISUAL SENSE USED THE EYE AS AN INSTRUMENT.

In order to make the experiment on how the visual sense gets the image of the objects from its instrument—the eye—a ball of glass will be made with a diameter of . . . (the mechanics of construction of the "contact lens" follows) . . . you will see that this instrument sends out the images . . . to your eye, as the eye sends them to the visual senses.

The reader will obviously note from the above, that Leonardo was making a schematic eye (Fig. 1A). In brief, a large thin walled glass ball was filled with water. An aperture simulating the iris was placed in this aqueous medium and a smaller thin walled glass ball, the crystalline lens, (also filled with water and probably having little optical effect on the system) was suspended within the larger ball. This

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Fig. 1. Leonardo da Vinci's Contact Lenses. Part A (left) is taken from Folio 3 verso, and part B (right) from Folio 7 verso. Photographic copy courtesy Elmer Belt Library. (Hofstetter & Graham.)

gigantic apparatus was obviously positioned with the "cornea" pointing downward, and the observer viewing what might be called the retinal imagery by placing his own eyes under the surface of the fluid hence creating a contact lens. From data available in the Hofstetter and Graham article,[1] it is possible to show that the viewing eye was within the focal point of the schematic optical system.

In order to understand the concepts behind this device, let us now turn briefly to Leonardo's thoughts on the nature of vision. He states his view concisely in Folio 2, verso.[2]

HOW THE IMAGES OF ANY OBJECT WHICH REACH THE EYE THROUGH A HOLE, IMPRINT THEMSELVES UPSIDE DOWN ON ITS PUPIL AND THE VISUAL SENSE SEES THEM UPRIGHT.

The pupil of the eye which gets through a very small round hole the images of the bodies situated beyond said little hole, always gets them upside down, but always the visual power sees them upright as they are. And this happens because said images pass through the center of the crystalline sphere situated in the middle of the eye; in this center they converge in one point, then they spread out over the opposed surface of this sphere without bending, and over said surface the images become upright like the objects from which they come. From there they are received by the visual power and transmitted to the mind where they are perceived.

Thus, he believed, that the imagery of the eye was *erect* and he hypothesized that the rays of light cross the optic axis twice in order to provide the proper relationships, i.e., left objects falling on the left side of the retinas, etc. If we investigate the visual studies of that period one finds that the researchers were beset with this problem of correct subjective appreciation of visual space or "psychic utilization."[3] Actually the world had to wait until the late 16th and early 17th century, almost a hundred years after the work of Leonardo, before inverted retinal imagery was finally accepted as fact. The first correct interpretation was made by Felix Platter (1536-1603) in 1583.[3] In 1604 these theories were expanded and formalized by John Kepler (1571-1630),[3, 4] whose eloquent work remains today as one of the fundamental pillars of physiological optics. One might well imagine the philosophical impact of this finding at the time.

The schematic eye of Leonardo da Vinci, therefore, had to produce erect imagery in some manner in order to achieve the desired proof of his theory of vision. As has been quoted above, he was able, by placing his eye under the fluid surface, to show how the visual power receives erect images.[5] But, by immersing his eye in the water, he was merely negating the power of his own cornea and substituting in its place the front surface of his large schematic eye. The erect imagery made possible by this lens system was simply the imagery of his own eye. Consequently, since Leonardo apparently misinterpreted the theory and nature of this device, one can hardly credit him with contact lens discovery based on this part of his experimental work, although it cannot be

denied that this was, in truth, a contact lens. This however, represents an ingenious mistake on his part, for it enabled him to demonstrate his theory of erect imagery.

In another section of the same "Codex of the Eye" Leonardo describes directions (Folio 7, verso) for the preparation of smaller glass containers designed to hold water and to be applied to either one or both eyes.[1] These lenses bear a closer resemblance to the contact lens of today, and did not contain the artificial crystalline lens or pupil. Apparently the small ones were applied directly to the orbital region with the subject in a standing position. The only hints as to his intent are contained in brief descriptions referring to some of the drawings.[1] (Figure 1B.) The first, "Break a ball of glass and with the convex part of it make a mask full of water and you will see that it is true what is described below." However, if one looks "below" in the remainder of folio 7, verso, and in the immediately succeeding folios,[2] one finds only further discussion of his theories on the nature of imagery of the eye.

In another caption he states:

> Make little round ampulses like this (Figure 1B Bottom), then cut them like glasses are cut with a hot piece of iron and make shells of half sphere like this (refers to drawing). Then use them for your glasses full of water like this (refers to drawing) and fill only one with water.

What does he mean by glasses? We must be careful before attaching common modern usage to this term. Interestingly Ferrero[2] makes a point of showing an illustration of Leonardo's primitive and crude visualization of the spectacle frame. Further, although in existence, spectacles were not in common use. Seemingly, therefore, "glasses" probably does not imply spectacles. More likely he is referring to either magnifying "glasses" or perhaps to what one might call a reduced schematic eye in keeping with the remaining text. If the latter possibility is the proper interpretation, it is probable that it did not take Leonardo long to determine that his ball of glass filled with water (the "crystalline humor") and immersed in water had little effect upon his schematic eye. Thus this element may merely be eliminated from these later smaller forms of schematic eyes. If the former possibility, i.e., glasses may be interpreted as magnifying glasses, is the correct interpretation, he may indeed have come upon "the principle of the contact lens."[1] Hence, it is doubtful if one can ever conclusively answer the question as to whether he appreciated the nature or application of this discovery.

The author prefers not to make a definitive statement on this point. Rather, he would conclude that Leonardo used the first known contact lens, but that there is a reasonable question of doubt as to

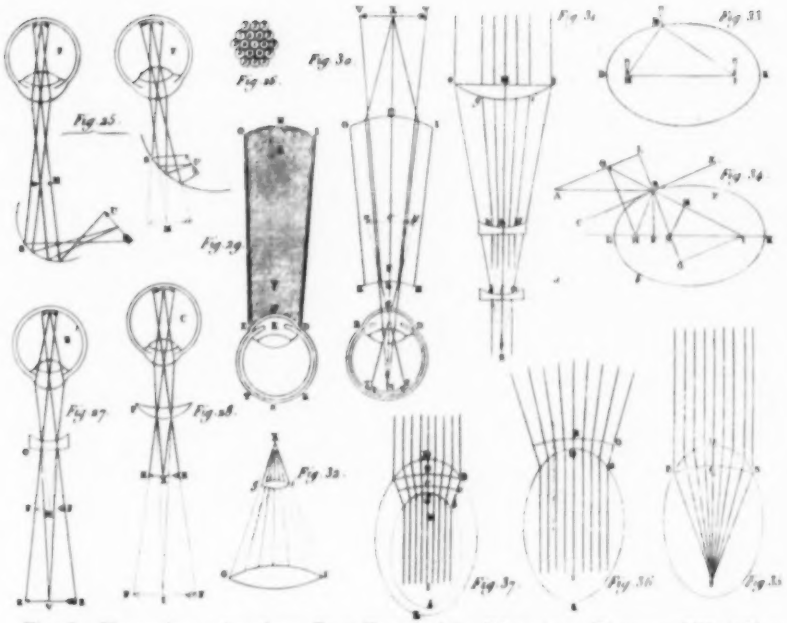

Fig. 2. Illustrations taken from René Descartes' La Dioptrique, Discourse VII, "Ways of Perfecting Vision." Fig. 29 represents the Descartes contact lens.

whether he appreciated the fundamentals of his "discovery." Thus it is felt that only partial credit of discovery should go to Leonardo for his initial use of the contact lens, and partial credit should go to Descartes, for his appreciation of the nature and optics of this visual aid and his application of the lens directly to the eye. (Figure 2, Descartes Figure 29), as shall shortly be demonstrated.

René Descartes' lens, which represents our second known contact lens was described in 1637 in his famed series of discourses, La Dioptrique.[6] Descartes, like Leonardo, was another of those rare geniuses who left an indelible mark on the history of modern man. He was an outstanding philosopher and scientist, making many important contributions in both fields. Interestingly, it is in his writings that we find the first concise statement of Snell's law. Further, Descartes was one of the group of researchers who objectively demonstrated the inverted nature of retinal imagery shortly after Kepler's famous theoretical study. It is seemingly appropriate, therefore, that he was the first one to fully appreciate the optics of contact lenses, the negation of the cornea, the magnification properties of lenses, and in a sense

some fundamental applications of the contact lens.

Previous references to the contact lens of Descartes appear in the writing of Dudragne,[5] and in a note in the Hofstetter and Graham study,[1] credited to Alpern.

The description of the Descartes lens appears in part of Discourse 7, entitled, "Ways of Perfecting Vision." In the section of this discourse which immediately preceeds the discussion involving the contact lens, the use of simple negative and positive meniscus lenses is discussed. (Figures 27, 28 of Figure 2.) Descartes was interested not only in the correction of ametropia and presbyopia but also in the magnification achieved by the use of auxiliary lenses, particularly that provided by the positive lens. Here he figuratively discussed its ability to make a flea into an elephant, and interestingly enough hints at the problem of size constancy. It is at this point that we find his discussion of the contact lens. (Figure 29 of Figure 2). He says:

> There remains only one other means for increasing the size of images, which is to cause the rays which come from various points of the object to cross as far as possible from the rear of the eye. But it is without comparison the most important and the most considerable of all, because it is the only one which can be used for inaccessible objects as well as for accessible ones and its effects have no limits; so that one can, by using it, increase the images more and more up to an indefinite size. For example, since the first of the three liquors with which the eye is filled causes almost the same refraction as ordinary water, if one applies directly against the eye a tube full of water, like EF, [Figure 29] at the end of which there is a glass GHI, whose shape is exactly like that of the skin BCD [cornea] which covers this liquor, and has the same relation to the distance from the rear of the eye, there will no longer be any refraction at the entry of this eye. But that which took place formerly, and which caused all the rays which came from a same point of the object to begin to curve, starting with that point in order to assemble on a same point on the extremities of the optic nerve, and which afterwards caused all those which came from diverse points to cross there in order to go to different points on this nerve, will take place from the entrance of the tube GI; so that these rays, crossing from there will form the image RST much larger that if they only crossed on the surface BCD, and they will form it larger and larger according to the increasing length of the tube. And thus the water EF performing the function of the humour K, the glass GHI, that of the skin BCD [cornea], and the entrance of the tube GI that of the pupil, vision will be made just the same as if nature had made the eye longer than it is over the whole length of this tube without there being a thing to notice, if not the fact that the true pupil would be not only useless during that time, but even damaging, in that it would exclude by its smallness the rays which could go towards the sides of the back of the eye, and thus will prevent the images from extending there, in as much space as they would, if the pupil were not so narrow. I also must not forget to warn you that the particular refractions, that are made a little differently in the glass GHI than in the water EF, are not at all considerable here, because this glass being equally thick all over, if the first of its surfaces makes the rays bend a little more than that of the water, the second straightens them out as much at the same time; and it is for this same reason that in the above I have not spoken of the refractions that the skins which envelope the humours of the eye cause, but only those of the humours.

As will be noted from the latter comments, this tube of water might be classed (as was Leonardo's) as an "afocal" contact lens, and that Descartes obviously correctly interpreted its optics. In the succeeding section he concedes the difficulty of "joining the water to our

eye" as well as the difficulty of determination of the front element curvature. He ultimately favored, as can be seen in Figures 30 and 31 of Figure 2, an instrument resembling a Galileon telescope to produce the desired magnification.

We believe that on the basis of this remarkable bit of work, much of the credit of discovery of the contact lens should go to René Descartes. Without meaning to detract from the genius of Leonardo, there apparently is little comparison between the two, as to a grasp of the problem and an appreciation of the implications. Yet, one must concede that great progress had been made in all phases of optics during the century which separated the two men and that an analysis such as Descartes' could hardly have been made in Leonardo's day. In addition, Descartes was the first to place a lens directly on the eye.

The third recorded contact lens was described by Thomas Young whose work appeared more than 150 years after that of Descartes. His primary interest was the determination of the seat of astigmatism and accommodation. Unfortunately his astigmatism was lenticular, so that as a result of his investigations he ascribed both astigmia and accommodation to the crystalline lens. Nevertheless this represented both the first account of ocular astigmatism[7] and a definitive step in our knowledge of the accommodative site. This famous and often quoted paper appeared in the PHILOSOPHICAL TRANSACTIONS in 1801. A discussion of this work as it bears on contact lenses appears in articles by Endore[7] and Alpern.[8]

The following is the account of Young's efforts:

> But, a much more accurate and decisive [discussing his studies on astigmia and a method of removing the cornea as a refractive element] experiment remains. I take out of a small botanical microscope a double convex lens, 8/9 radius and focal distance, fixed in a socket 1/5" in depth; securing its edges with wax, I drop into it a little water, nearly cold, till it is 3/4 full, and then apply it to my eye, so that the cornea enters half way into the socket, and is everywhere in contact with the water. My eye immediately becomes presbyopic, and the refractive power of the lens, which is reduced by the water to a focal length of about 16/10th, is not sufficient to supply the place of the cornea, which has been disqualified by the intervention of the water; but the addition of another lens, of 5½" focus, restores my eye to its natural state, and somewhat more. I then apply the optometer, and I find the inequality in the horizontal and vertical refractions as without the water [his lenticular astigmia]. At first the accommodation appears to be somewhat less . . . and this made me once imagine that the cornea might have some small effect in the natural state; but considering the artificial cornea was about an eighth of an inch before the place of the natural cornea, I calculated the effect of this difference, and found it exactly sufficient to account for the dimunition of the range of vision.

In reading the above passage by Young the reader will no doubt discern a resemblence between Descartes' lens and Young's lens. The main difference is that Young used a small tube and a double convex lens rather than a long afocal container, and apparently did not attempt to secure the tube to the eye itself. It is difficult to ascertain if Young

had access to or knowledge of the work of Descartes, or if this was an original development of his own. By means of an auxiliary lens he was able to correct his refractive error. Unfortunately Young apparently failed to perceive the implications of this device in the routine correction of ametropia. At a later date, in 1897, this general type of optical aid, i.e., a corrective contact lens worn completely external to the eyelids, was called the "Hydrodiascope" by Lohnstein, (and later also by Siegrist),[9,10] and attempts were made to utilize it in correcting visual defects.

In general, it can be said that the preceding material indicates that the name of René Descartes deserves a more prominent place in the history of contact lenses. There would seem to be no doubt that his was the major contribution prior to modern times.

If one reviews the factors which were discussed, one finds each of the three investigators made a significant contribution.

Leonardo used the first known contact lens; however, he may not have appreciated the nature of his discovery.

Descartes was the first to apply the lens directly to the eye and to correctly interpret contact lens optics, imagery, magnification and the negation of the cornea by the lens. He also suggested some possible applications of the lens.

Thomas Young was apparently the first to correct an error of refraction using a combination contact lens and auxiliary lens.

In these investigations, one cannot help finding interest in the interrelationship between all phases of visual science. Here, in a simple review of three early contact lenses, one finds closely allied studies dealing with the relationship between external space and the retina, the nature and correction of the image forming apparatus of the eye, the magnification properties of lenses and the eye, size constancy, astigmatism, and accommodation. It is upon such fundamental studies that we have constructed our current concepts of the visual process.

In conclusion, the author wishes to quote the closing sentence from Descartes' discourse WAYS OF PERFECTING VISION.[6] From this, one may gather that in addition to receiving credit for his efforts as regards contact lenses Descartes also deserves designation as the first individual to differentiate between medical visual care and what might be termed optometric visual care. He notes that the eye apparently has the ability to change with practice effects—this conclusion being based upon the excellent distance vision of the sailor and hunter, upon the skill of artisans and engravers at recognition of extremely fine detail and upon the Indian's ability to gaze at the sun for extended periods.

He believes these individuals are able to perform these changes by means of gradual variation of pupil size, or by changing the shape of the crystalline humor (lens), which like the iris "skin" is thought to be muscular. He then states:

> But these things belong rather to medicine, whose purpose is to remedy the defects of vision by the correction of natural organs, and not to dioptrics, whose purpose is to remedy these same defects by the application of some other artificial organs.

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ANNOUNCEMENT

BLUR OF THE RETINAL IMAGE, BY GLENN A. FRY

"Blur of the Retinal Image" is the title of a book just published by the Ohio State University Press. Author of the monograph is Dr. Glenn A. Fry, famed researcher in vision, Professor of Physiological Optics, Director of the School of Optometry and Co-Director of the Institute of Research in Vision at the Ohio State University.

The work is a direct extension of Helmholtz's studies on the light distribution on the retinal image, and takes into account such factors as diffraction and spherical aberration. It is the outcome of many years of theoretical study by the author and will probably go down as one of the fundamental contributions in this field.

Made up of 33 pages of introduction and 120 pages of text, including 53 illustrations, the book sells for $3.50 and is obtainable from the Ohio State University Press, Columbus 10, Ohio.

THE EFFECT OF LUMINANCE, TARGET CONFIGURATION AND LENSES UPON THE REFRACTIVE STATE OF THE EYE*

PART II

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INTRODUCTION

Part I of this study described the determination of the two targets which would elicit an adequate and an inadequate accommodative response, respectively, under certain specified conditions of luminance. Since procedures and apparatus were outlined in Part I, the present discussion will be limited to instrumentation and methods employed in that part of the investigation to be dealt with below. The objective of this final stage of the research project was to determine what quantitative change in accommodative response would occur under various luminance levels when each of six observers fixated each of the above-mentioned targets.

PROCEDURES AND APPARATUS

As will be recalled from Part I, the Snellen "E" was designated as the adequate stimulus and the blank wall the inadequate stimulus. Each of these two targets was viewed at a distance of twenty feet from the observer under the following luminance levels: 0, 0.001, 0.01, 0.10, 1.0, 10, 100, and 300 foot-lamberts. The zero level of luminance was attained by turning off all luminaires in the laboratory whose construction was intended to prevent the entry of external light into the room. The remaining luminance levels were attained by various combinations of filters and luminaires, as described in Part I.

The targets were viewed by the subjects with neither auxiliary nor correction lenses before the eye since the observers selected for this part of the investigation were emmetropic, or nearly so. The six

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Part I of the report appeared in the January, 1956, issue.
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observers were male students of the Los Angeles College of Optometry in their early twenties. Clinical tests performed on each subject by the senior author showed the accommodative amplitude, the near and far phorias, and the AC/A ratio to be within normal limits. Each observer was either naturally emmetropic or within ±0.25 diopters of this state, either in sphere or cylinder.*

Measurements of accommodative response were made monocularly using both the infrared skiascope and the modified haploscope. Luminance levels above 10 foot-lamberts employed in this study did not permit the use of the infrared skiascope, because the amount of constriction of the subject's pupil in response to this magnitude of light flux made detection of the fundus reflex in infrared skiascopy nearly impossible. Consequently, at the 100 and 300 foot-lambert levels, the modified haploscope had to be used to measure changes in the refractive state. This, of course, introduced a complication by virtue of the fact that the two instruments do not measure the refractive state in quite the same way. Fry had found that the research skiascope under-represents the amount of minus by about 0.50 diopters,[22] whereas Morgan notes an over-representation in minus of between 0.50 and 1.00 diopter by the haploscope,[23] when the findings are compared to those obtained by conventional retinoscopy. Thus, instrumental idiosyncrasy can account for a difference on the order of 1.00 to 1.50 diopters when the refractive state of a subject is measured.

Therefore, by using these two instruments at the several luminance levels, we feared that the artefact discussed above would result in a spurious increase in accommodation at the higher levels of luminance. It was necessary, as a result, to eliminate this complication in order to evaluate correctly refractive changes at the higher luminance levels.

To accomplish this, measurements on the six subjects were made at 1 foot-lambert and at 10 foot-lamberts with both the infrared skiascope and the modified haploscope, and the findings compared in several ways, as indicated below, under the examination of results.

The data obtained in this phase of the investigation were subject to both graphic and statistical analysis.

*Haploscopic and infrared skiascopic determination of the refractive state makes it very desirable, of not absolutely necessary, that the subjects be essentially emmetropes. If lenses are used to make the ametropic observes artificially emmetropic (as would be required for our modified haploscopic examination), the reflection of light off the lenses seriously interferes with the determination of the fundus reflex in infrared skiascopy. Furthermore, lenses worn by some and not by other observers would create variations in perceived luminance of the object, especially at reduced luminance levels, since lenses cut down the transmission of light by at least ten per cent.[21]

RESULTS

The data showed the haploscopic representation of the refractive state, based upon the arithmetic mean of the two depth of focus boundary values, to between 0.50 and 1.00 diopter more negative than the comparable infrared skiascopic findings at the two luminance levels permitting the use of both instruments. This suggested that a +0.75 diopter correction, added to the haploscope readings, would bring the latter into closer correspondence with the infrared skiascope readings (which seemed more closely to approximate the subjectively determined refractive state of the observer).

However, it was found that, if one used the haploscope data derived from determination of the hyperopic end of the depth of focus range delineated by this instrument, the results were in as close agreement with the infrared skiascope readings as if a correction factor were added to the arithmetic mean of the two limits of the depth of focus. These results are shown graphically in Figures 11 through 16.* In Figures 13 and 14 will be seen the abrupt change to a negative refractive state at the 100 and 300 foot-lambert levels. Since there is no such trend toward negativity displayed at the lower levels of luminance, this abrupt change at the levels where the modified haploscope was employed suggests the artefactual nature of the response, and further confirms Morgan's observations concerning the over-representation of the refractive state in a minus direction by the haploscope.

When the above suggested 0.75 diopter correction factor is added to the haploscope findings based on the mid-point of the depth of focus range, the results reveal no clear-cut trend in the refractive changes at the higher luminance levels. (See Figures 15 and 16.) Undoubtedly, this is because the difference between these findings and those derived from the use of the infrared skiascope are not of a consistent magnitude. Although the differences tend to be on the order of 0.50 to 1.00 diopter.

*It will be observed that, in Figures 12, 14, and 16, the lowest luminance level is not 0, but 0.001 foot-lamberts. The reason for this is that the Snellen "E" target is not visible at the zero luminance level, so that the response would be essentially to the blank wall against which the "E" was mounted. This response is graphically shown in Figures 11, 13, and 15.

Fig. 11. Mean accommodative response values of six observers to a blank wall under several luminance levels (0-10 foot-lamberts; Infrared skiascope used 100-300 foot-lamberts; Haploscope used—hyperopic limit).
Fig. 12. Mean accommodative response values of six observers to a Snellen "E" under several luminance levels (0.001-10 foot-lamberts; Infrared skiascope used; 100-300 foot-lamberts; Haploscope used—hyperopic limit)
Fig. 13. Mean accommodative response values of six observers to a blank wall under several luminance levels (0-10 foot-lamberts; Infrared skiascope used; 100-300 foot-lamberts; Haploscope used—mean of depth of focus range)

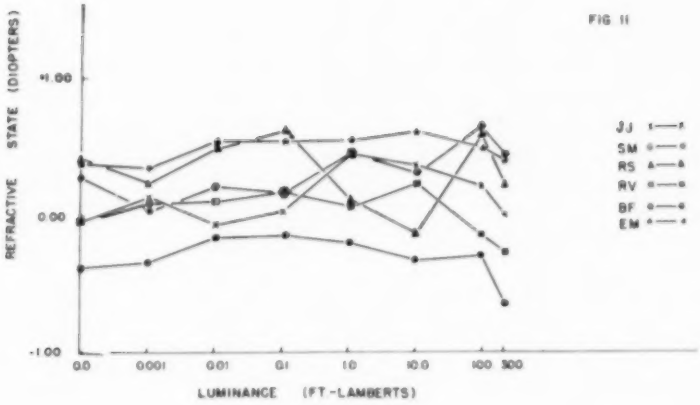
FIG. 11
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.0
0.0001
0.001
0.01
0.1
1.0
10.0
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

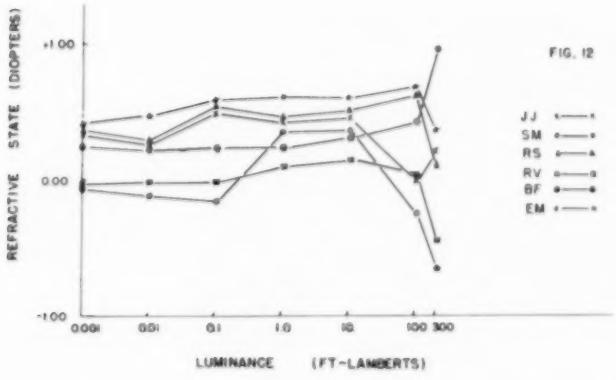
FIG. 12
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.001
0.01
0.1
1.0
10
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

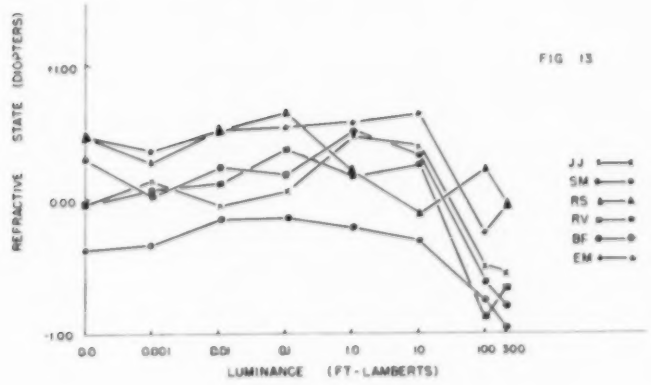
FIG. 13
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.0
0.0001
0.001
0.01
0.1
1.0
10
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

in some cases the difference is less, in other cases, more. Application of a 0.75 diopter correction factor therefore tends to enhance some of the differences and to obscure others. Consequently, it was felt that using the haploscope data representing the hyperopic end of the depth of focus interval (Figures 11 and 12) constituted a more satisfactory procedure. In the latter case, the trend of refractive change with luminance level is not obscured, nor is it exaggerated as in the case where either the uncorrected mean haploscopic values or worse, the values representing the myopic end of the depth of focus interval are used.

Consequently, the refractive data to which statistical analysis was subsequently applied were those figures obtained with the infrared skiascope at the levels of luminance below 100 foot-lamberts, and those threshold values obtained with the modified haploscope set at the hyperopic end of the depth of focus interval at the 100 and 300 foot-lambert levels.

The significance of the differences in magnitudes of the refractive state at each level of luminance, for each target, was computed for each observer. The technique employed was the Fisher t-ratio,[24] the assumption being made that the means whose differences were being analyzed were uncorrelated.

The results are summarized in Table IX, which presents the refractive state of each observer at each luminance level for both targets, the Snellen "E" and the blank wall, and also indicates which responses differ significantly from the others. In the Table, all figures enclosed by parenthesis are significantly more plus (that is, reveal less accommodation in play) than those values either enclosed by brackets or not enclosed. The figures enclosed by brackets, in turn, are significantly more plus than those values not enclosed.

Table X shows the absolute magnitude of the difference in refractive state revealed by each observer with reference to each of the two targets viewed. In the left-hand column of each half of the Table, each figure represents the difference between the refractive states at moderate and at low luminance levels. The figures in the respective right-hand columns show the differences in the refractive state between

Fig. 14. Mean accommodative response values of six observers to Snellen "E" under several luminance levels (0.001-10 foot-lamberts; Infrared skiascope used; 100-300 foot-lamberts; Haploscope used—mean of depth of focus range).
Fig. 15. Mean accommodative response values of six observers to a blank wall under several luminance levels (0-10 foot-lamberts; Infrared skiascope used; 100-300 foot-lamberts; Haploscope used—mean range +0.75 D. correction factor.)
Fig. 16. Mean accommodative response values of six observers to Snellen "E" under several luminance levels (0.001-10 foot-lamberts; Infrared skiascope used; 100-300 foot-lamberts; Haploscope used—mean range +0.75 D. correction factor).

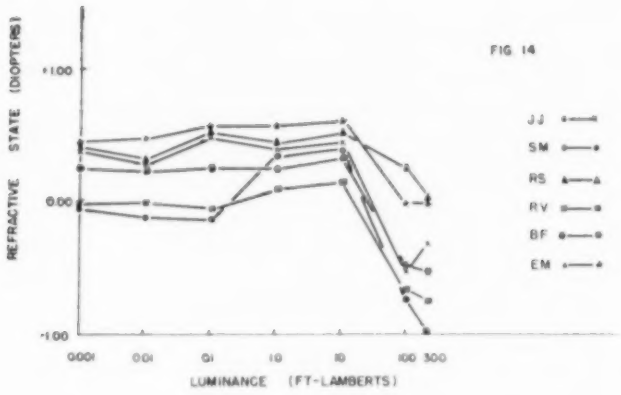
FIG. 14
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.0001
0.001
0.01
0.1
1.0
10
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

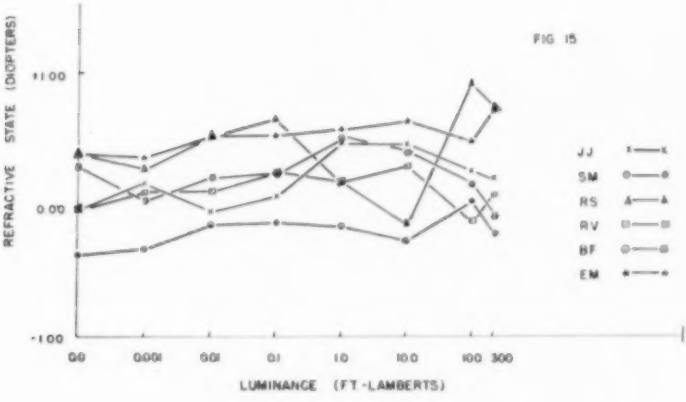
FIG. 15
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.0
0.0001
0.001
0.01
0.1
1.0
10.0
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

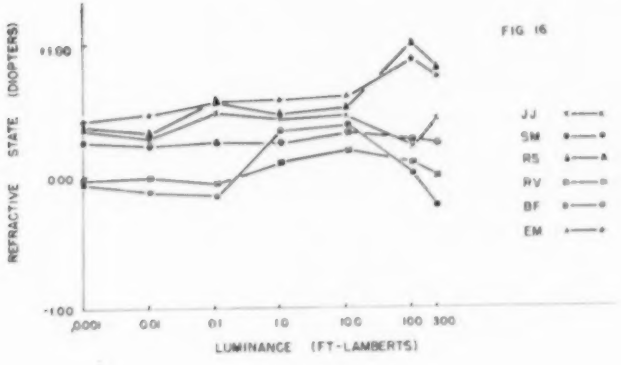
FIG. 16
REFRACTIVE STATE (DIOPTERS)
+1.00
0.00
-1.00
0.0001
0.001
0.01
0.1
1.0
10.0
100
300
LUMINANCE (FT-LAMBERTS)
JJ
SM
RS
RV
BF
EM

TABLE IX

Refractive State of Six Observers at Various Levels of Luminance for Two Separate Targets.

Luminance Level		0.00	0.001	0.01	0.10	1.80	1.10	100*	300*		0.001	0.01	0.10	1.8	11.0	100*	300*
Target						blank wall								Snellen "E"			
Subject																	
J.J.	$\bar{X}$	—0.01	+0.16	—0.06	+0.05	(+0.48	+0.39)	+0.22	+0.02	$\bar{X}$	+0.35	+0.28	(+0.49	+0.41	+0.45)	0.00	+0.20
	σ	0.25	0.39	0.26	0.16	0.14	0.16	0.08	0.06	σ	0.17	0.19	0.11	0.22	0.24	0.11	0.12
R.V.	$\bar{X}$	—0.02	+0.11	+0.10	(+0.20	+0.14	+0.27)	—0.11	—0.25	$\bar{X}$	—0.04	(—0.02)	—0.05	(+0.10	+0.18	+0.07)	—0.43
	σ	0.16	0.15	0.20	0.13	0.23	0.18	0.14	0.13	σ	0.22	0.33	0.22	0.27	0.22	0.15	0.10
R.S.	$\bar{X}$	+0.41	+0.27	+0.30	(+0.67)	+0.16	—0.14	(+0.60)	+0.27	$\bar{X}$	+0.37	+0.31	[+0.52	+0.45	+0.53]	(+0.65)	+0.11
	σ	0.18	0.31	0.18	0.13	0.32	0.19	0.17	0.13	σ	0.20	0.23	0.15	0.23	0.13	0.16	0.19
S.M.	$\bar{X}$	—0.39	—0.34	(—0.14	—0.15	—0.17)	[—0.29	—0.26]	—0.64	$\bar{X}$	—0.07	—0.12	—0.14	(+0.36	+0.39)	[+0.13]	—0.32
	σ	0.26	0.27	0.25	0.27	0.26	0.23	0.13	0.05	σ	0.13	0.24	0.25	0.21	0.30	0.12	0.06
B.F.	$\bar{X}$	+0.29	+0.06	+0.21	+0.19	(+0.50)	+0.35	[+0.63	+0.48)	$\bar{X}$	+0.26	+0.24	+0.25	+0.26	+0.35	+0.41	(+0.92)
	σ	0.29	0.19	0.25	0.16	0.16	0.15	0.29	0.34	σ	0.16	0.25	0.13	0.20	0.13	0.26	0.14
E.M.	$\bar{X}$	+0.40	+0.34	+0.52	(+0.84	+0.57	+0.64	+0.52)	—0.45	$\bar{X}$	+0.40	+0.46	+0.54	+0.56	(+0.60	+0.69)	+0.37
	σ	0.10	0.30	0.14	0.18	0.18	0.12	0.20	0.24	σ	0.17	0.17	0.16	0.12	0.20	0.20	0.26

*Accommodative response determined by haploscope at this luminance level. Value represents most hyperopic end of depth of focus range. Values at all other luminance levels determined by infrared skiascope.
Figures in parenthesis represent significantly least amount of accommodation.
Figures in brackets represent significantly more accommodation than figures in parenthesis, but significantly less accommodation than remaining values represent.

TABLE X

Maximum changes in accommodative response to two separate targets by six observers between moderate vs. high, and moderate vs. low levels of luminance.

Target	Blank Wall		Snellen "E"	
Subject	Moderate-low luminance	Moderate-high luminance	Moderate-low luminance	Moderate-high luminance
J.J.	0.54 D	0.46 D	0.21 D	0.49 D
R.V.	0.29 D	0.52 D	0.22 D	0.61 D
R.S.	0.40 D	0.40 D	0.34 D	0.54 D
S.M.	0.25 D	0.50 D	0.53 D	0.71 D
B.F.	0.58 D	*	0.68 D	*
E.K.	0.54 D	0.37 D	0.96 D	0.46 D
Total	2.60 D	2.25 D	2.94 D	2.81 D
Average Change	0.43 D	0.45 D	0.49 D	0.56 D

* Least accommodation shown at 300 ft. lambert level of luminance.

the moderate and high luminance levels. At the bottom of the Table are shown the average differences exhibited between the different luminance levels for the two targets observed.

The results seem to show that, at the lower levels of luminance—0, 0.001, and 0.01 foot-lamberts—there is about 0.50 diopter significantly more accommodation in play, the range being from about 0.25 to 0.75 diopters. This also holds true for the highest level of luminance, 300 foot-lamberts. The least accommodation seems to occur between 1 and 100 foot-lamberts. At levels above and below these limits, approximately one-half diopter more accommodation appears to come into play. Since the figures employed represented the most plus findings, it may reasonably be concluded that the 0.50 diopters of accommodation is not an artefact.

DISCUSSION

The present investigation, by virtue of the Air Force contract under which it was undertaken, was limited to the analysis of only two variables: luminance level and target configuration. The appraisal of refractive changes, however, leads to the belief that target size and object-background contrast in luminance are of equal importance in affecting the refractive state and their influence cannot be neglected in a definitive study of nocturnal and sky myopia.

Stress was laid on the fact that the targets appeared to exert differential effects on the accommodative response at the different luminance levels. This may be due to a change in the depth of focus of the observer's eye with a change in the level of illumination.* In measure-

*Artificial pupils to control this variable were not employed, since the intention here was to simulate conditions which might be encountered by pilots, who, presumably, would not be wearing such devices. However, it is desirable that the effect of artificial pupils be analyzed in further studies of this nature.

ments made with the haploscope, such a shift would be most significant, since what is determined by this instrument is the depth of focus interval. Consequently, it remains to be ascertained whether either or both boundaries shift with changes in luminance level, and whether such changes are equal and systematic. It should be recalled that the haploscope tends to over-represent the myopic shift, and the infrared skiascope to under-represent it.

It was also found in this investigation that minus lenses may further induce, rather than merely measure, the accommodation in play under the several testing conditions. It would therefore seem unwise to rely on such lenses to compensate for the myopic shift. Further, the marked reduction in the amount of light reaching the eye under very low luminance levels would be exacerbated by the wearing of lenses, which reduce the transmission of light to the eye by a minimum of ten per cent. It is also evident that the application of minus lenses to an esophoric subject having a high AC/A ratio might blur, rather than clear, his vision. These considerations would seem to preclude the use of minus lenses to compensate for the 0.50 to 0.75 diopters of accommodation which appear to come into play at luminance levels below 1 foot-lambert or above 100 foot-lamberts.

SUMMARY

A two-part investigation was undertaken under contract with the Air Force. The first phase utilized three observers who observed six arbitrarily-chosen targets through various powered lenses under a high, medium, and low level of luminance. The responses were analyzed by means of the coefficient of concordance to determine whether each target promoted similar responses within and between observers under the different testing conditions. This was done to find out whether any target gave consistently better agreement between the magnitude of the accommodative response to that target and the magnitude of the stimulus represented by the lens power through which the target was observed.

The responses were also tested by the method of variance analysis to determine which targets occasioned the most and the least variability in the observers' responses. On the basis of the foregoing appraisals the Snellen "E" was judged to be the most effective and the blank wall the least effective in promoting adequate accommodative responses.

In the final phase of the investigation, the two targets were presented to six more or less emmetropic observers, none of whom had participated in the initial stage of the study. These six subjects fixated

the targets at luminance levels ranging from zero up through 300 foot-lamberts. Responses at the lower levels were measured with the infrared skiascope and at the higher levels with the modified haploscope. The equivalence of the responses obtained by these two methods was determined. The data were then subjected to a statistical examination by the Fisher t-ratio method, on the basis of which it was concluded that, at luminance levels much below 1 foot-lambert or above 100 foot-lamberts, significantly more accommodation comes into play. The magnitude of this response is of the order of 0.50 diopters, with a range of roughly 0.25 to 0.75 diopters.

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ANNOUNCEMENT

NATIONAL BOARD OF EXAMINERS IN OPTOMETRY

The dates of the National Board Examinations are scheduled for Wednesday and Thursday, May 16 and 17, 1956, as follows:

Wed.—May 16		
8:30—11:30 A.M.	Part II, Section I, Visual Science II
1:00— 4:00 P.M.	Part I, Section I, Visual Science I
4:30— 5:30 P.M.	Part II, Section V, Social, Legal, Economic and Professional Aspects
7:00—10:00 P.M.	Part I, Section II, Theoretical Optics
Thurs.—May 17		
8:30—11:30 A.M.	Part II, Section II, Theory and Methods of Optometry
1:00— 3:00 P.M.	Part I, Section III, Anatomy of the Eye
3:30— 5:30 P.M.	Part II, Section III, Ophthalmic Optics
7:30— 9:30 P.M.	Part II, Section IV, Diseases of the Eye

Undergraduate students in professional optometric courses in our schools and colleges may apply to take their National Boards through their school administrative officers. Examinations will be given at all schools and colleges.

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GEOGRAPHICAL ROSTER OF ACADEMY MEMBERS

In this issue of the JOURNAL we present the 1956 geographical roster of Academy members. Numerically, the Academy is a growing professional society, composed of approximately 750 optometrists and other specialists in visual science, ophthalmic optics and education. The majority of members are optometrists in either general optometric practice or in one of the specialities. All of these men have demonstrated their interest and ability in the more advanced studies of the science by completing special qualifying work for Fellowship, and by the high standards maintained by them in their practices.

Each of the members has made or is now making contributions to the advancement of optometry. Their combined efforts have helped to place the profession in the position of being one of the important fac-

tors in the family of healing arts professions. Each Academy member is expected to live and practice, at all times, in such a manner as to exemplify the high professional standards of optometry and thus, by his example, enhancing interprofessional relationships.

As was stated years ago,* the Academy has slowly grown into a vital force for professional conduct, proper undergraduate education and a thoroughly proven and accepted ocular science as a basis for the practice of optometry. The character of this organization as indicated by its founders, and consistently upheld by its membership and its history, is of a technical and educational, rather than of an economic or promotional nature. In this respect it has always been most fortunate in the possession of a loyal membership which has been deeply concerned in optometry's welfare and in perpetuating and protecting the professional associations which must accompany the future development of optometry. The membership of the American Academy of Optometry, changing gradually over the years, reflects the successive leadership in our profession.

The list of members as presented elsewhere in this issue is of particular value to all the 7,000 readers of this JOURNAL, as it affords a basis for making the most qualified professional referrals when patients move from one part of the country to another. We also hope that the published list will encourage other optometrists to join as new members, and work with those already active in a number of excellent Academy projects.

CAREL C. KOCH

*Statement by Executive Council, American Academy of Optometry, 1944.

CURRENT COMMENTS

Terry Judith Parkins
Editorial Assistant

Optometrists will confer a favor by sending news items of general interest for this department; such as relate to new instruments, clinical techniques, education, visual health and optometric legislation and organization.

NEWS BRIEFS

The Wisconsin Optometric Association will hold its annual meeting at Eau Claire, May 12-14. . . . Mr. Donald F. Southgate, president of Shuron reports 1955 sales up 21 per cent over 1954. The Company is now launching a national advertising campaign to stress the importance of periodic eye care. The first ad appeared in the POST in January. . . . The Eastern States Optometric Congress will be held in New York

City, April 8-10. . . . Bausch & Lomb has announced a new automatic motor driven refractive chair and also a new plastic spectacle frame built to accommodate a hearing aid in each temple. . . . The Oklahoma Optometric Association will hold its annual meeting at Tulsa, April 8-10. . . . Dr. Harold S. Bobb has been installed as Worshipful Master of Columbine Lodge #147, A.F. & A.M. of Denver. . . . The Better Vision Institute advertising campaign, "Tune Up—Dress Up Your Priceless Eyes—See Your Examiner Soon," is in high gear. Ads in the POST and VOGUE, plus radio and television are doing a great job in directing attention towards visual problems. . . . Dr. Mat Alpern is now working with the Vision Research Laboratory, University of Michigan, Ann Arbor. . . . Dr. Robert E. Bannon, secretary of the Aniseikonic Forum, American Optical Company, Southbridge, reports he is planning a Spring Seminar on Aniseikonia. Optometrists wishing to attend should write for details at once. . . . The Upper Mid-West Council for Better Vision is running a series of excellent newspaper ads to promote eye care. These ads, sponsored by a group of laboratories, are appearing in every daily newspaper in Minnesota. The Kahn Optical Company, Toronto, is doing a similar job in 20 of the leading Canadian daily newspapers. . . . The Trustees of Illinois College of Optometry mailed a copy of the college financial report to all alumni. . . . Professor Ernest Barnay of the University of Upsala, Sweden, spoke before the New York Academy of Optometry. His subject was, "Monocular and Binocular Visual Acuity and Statistics Behind the Visual Acuity Test." Members of the Eastern Pennsylvania and the New Jersey Chapters were invited. . . . Dr. Gerald Westheimer, Columbus, was elected 1956 president of the Central Ohio Chapter of the Academy. . . . The Korector Sales Company, 6824 W. Lake St., Minneapolis, has just issued a new illustrated 28-page monograph dealing with the Arneson Korector. A copy will be sent upon request. . . . Dr. Samuel Renshaw, professor of experimental psychology at The Ohio State University has received the Navy's Distinguished Public Service Award for his work in visual perception during World War II. . . . Dr. James F. Wahl, dean, College of Optometry, Pacific University and Dr. George F. Newhouse, The Dalles, Oregon, have been presented certificates of Life Membership in the Oregon Optometric Association. . . . Dr. Carl A. Radde, 80, Cleveland, died January 26. Dr. Radde translated into English Ewaldt Hering's works on Physiological Optics. This translation was published by the Academy and has had world-wide distribution.

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The program of a sixth year leading to a Doctorate of Optometry degree is open to graduates of other schools of optometry who possess an academic bachelor's degree. The University of Houston College of Optometry welcomes inquiries concerning this special program towards the Doctorate of Optometry degree. The regular five-year program at the University of Houston leads to a Bachelor of Science degree at the end of the fourth year and to a Certificate of Completion in Optometry at the end of the fifth year which meets the legal requirements for the practice of optometry. The Doctorate of Optometry degree is granted for an optional sixth year.

ASSOCIATION OF SCHOOLS AND COLLEGES OF OPTOMETRY

The annual meeting of the Association of Schools and Colleges of Optometry will be held at Miami, Florida, June 17-18. These A.S.C.O. dates follow the annual Congress of the American Optometric Association which will be held in the same city. Dr. Morton Abram, Illinois College of Optometry, has been appointed chairman of the Committee on Arrangements for the A.S.C.O. meeting, by president, Dr. Henry W. Hofstetter.

ANNOUNCING

You Are Invited to Our COMPREHENSIVE WESLEY-JESSEN FITTING SEMINARS

This year we are giving two types of courses. They are called courses A and B. The A Course will be a beginning course in the fitting of the Wesley-Jessen Microlenses. The B Course will be for those who have formerly taken the Wesley-Jessen Course or for those who are familiar with our method of fitting the lens. The B Course will cover the latest developments in the field, and it will cover also specialties such as Cosmetic Contact Lens fitting, Telescopic fitting, and Keratoconus fitting. We plan to make the B course a permanent part of our service to the fitters in the field. In this manner, we plan to have a complete service to the men in the field. BE CERTAIN THAT YOU SIGN UP FOR THE RIGHT COURSE.

Spring **1956** *Schedule*

February 1 to June 10

Note: **Encircle the course date on your calendar.**

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eekdays 3:30 p.m. to 5:00 p.m.

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you have patients for us to see for her a beginning fitting or a consul-ion, please contact us beforehand an appointment. For these patients have set up a separate time. If the rse will be given during the week, clinic hours will be from 3:30 p.m. 5:00 p.m. If the course will be given a Sunday, the clinic hours will be m 10:30 a.m. to noon. BE SURE WRITE TO US BEFOREHAND R AN APPOINTMENT FOR UR PATIENT. *Also, do remember bring your patient's case history.*

SECOND PORTION SPRING SCHEDULE

STATE & CITY	DATE	TIME	TYPE COURSE	HOTEL
Kentucky:				
Louisville	Sun., April 15	1:00 p.m. to 5:00 p.m.	A & B	Henry Clay
Tennessee:				
Nashville	Sun., April 15	1:00 p.m. to 5:00 p.m.	A & B	Dinkler-Andrew Jackson
Knoxville	Mon., April 16	7:00 p.m. to 10:00 p.m.	A	Andrew Jackson Hotel
Chattanooga	Mon., April 16	7:00 p.m. to 10:00 p.m.	A	Hotel Patten
Georgia:				
Atlanta	Tue., April 17	7:00 p.m. to 10:00 p.m.	A & B	The Dinkler Plaza
North Carolina:				
Charlotte	Wed., April 18	7:00 p.m. to 10:00 p.m.	A	Hotel Charlotte
South Carolina:				
Columbia	Wed., April 18	7:00 p.m. to 10:00 p.m.	A	Hotel Columbia
Charleston	Wed., April 18	7:00 p.m. to 10:00 p.m.	A	Fort Sumter Hotel
West Virginia:				
Charleston	Fri., April 20	7:00 p.m. to 10:00 p.m.	A & B	The Daniel Boone
Ohio:				
Cincinnati	Sun., April 22	1:00 p.m. to 5:00 p.m.	A & B	Netherland Plaza
Columbus	Sun., April 22	1:00 p.m. to 5:00 p.m.	A & B	Deshler Hilton Hotel
Cleveland	Fri., April 27	7:00 p.m. to 10:00 p.m.	A & B	Hotel Statler
Akron	Fri., April 27	7:00 p.m. to 10:00 p.m.	A & B	Portage Hotel
Toledo	Wed., May 17	7:00 p.m. to 10:00 p.m.	A & B	Commodore Perry Hotel
Pennsylvania:				
Pittsburgh	Wed., April 25	7:00 p.m. to 10:00 p.m.	A & B	Hotel William Penn
Philadelphia	Wed., June 6	7:00 p.m. to 10:00 p.m.	A & B	Adelphia Hotel
Michigan:				
Detroit	Sun., May 20	1:00 p.m. to 5:00 p.m.	A & B	Hotel Statler
New York:				
Buffalo	Tue., May 22	7:00 p.m. to 10:00 p.m.	A & B	Hotel Statler
Syracuse	Wed., May 23	7:00 p.m. to 10:00 p.m.	A & B	Hotel Syracuse
Rochester	Thur., May 24	7:00 p.m. to 10:00 p.m.	A & B	The Sheraton Hotel
New York	Thur., June 7	1:00 p.m. to 5:00 p.m.	A & B	Hotel Roosevelt
Maryland:				
Baltimore	Sun., June 3	1:00 p.m. to 5:00 p.m.	A & B	Lord Baltimore Hotel
District of Columbia:				
Washington	Sun., June 3	1:00 p.m. to 5:00 p.m.	A & B	Hotel Statler
Virginia:				
Richmond	Mon., June 4	7:00 p.m. to 10:00 p.m.	A & B	Hotel John Marshall
Norfolk	Mon., June 4	7:00 p.m. to 10:00 p.m.	A & B	Commodore Moury Hotel
New Jersey:				
Newark	Thur., June 7	1:00 p.m. to 5:00 p.m.	A & B	The Douglas Hotel
Connecticut:				
Hartford	Sun., June 10	7:00 p.m. to 10:00 p.m.	A & B	Hotel Statler
Massachusetts:				
Boston	Sun., June 10	7:00 p.m. to 10:00 p.m.	A & B	Hotel Statler

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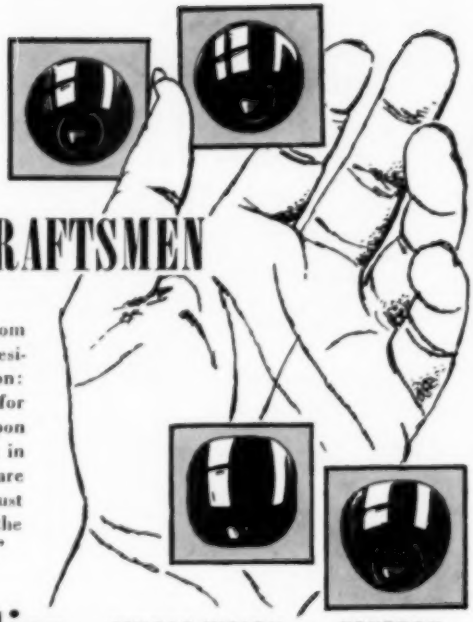

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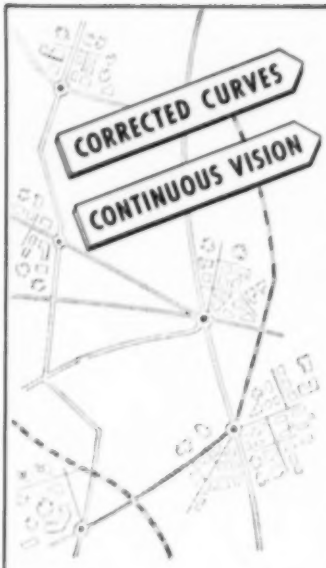

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